Urban Challenge

Route Network Definition File (RNDF) and Mission Data File (MDF) Formats

May 12, 2006

Defense Advanced Research Projects Agency
3701 North Fairfax Drive
Arlington, VA 22203-1714

Table of Contents

Route Network Definition File (RNDF) and Mission Data File (MDF) Formats

1.0 General Information

To meet the objectives of the Defense Advanced Research Projects Agency (DARPA) Urban Challenge, a team's vehicle must complete multiple missions over a defined route network. This document specifies the data formats DARPA will use to specify route networks and missions.

A 'route network' is defined as the set of accessible roads and areas in which an autonomous vehicle may travel. The Route Network Definition File (RNDF) specifies accessible road segments and provides information such as waypoints, stop sign locations, lane widths, checkpoint locations, and parking spot locations. The route network has no implied start or end point. In addition to road segments, the RNDF specifies free-travel 'zones' that have a defined perimeter, but for which no waypoints are provided. Zones are used to represent parking lots and areas with moving or stationary obstacles or vehicles.

The Mission Data File (MDF) provides a series of checkpoints that must be visited by a vehicle in sequence and other supporting information. A 'checkpoint' is a two-dimensional point on the earth specified by a latitude and longitude. The specific path between checkpoints through the route network is not specified. MDFs will be provided for use at site visits, the National Qualification Event (NQE), and the Urban Challenge final event.

The route network may have segments for which some information is not provided in the RNDF. For instance, the lane width or speed limit may be unspecified, the waypoints may be of low density, or a road defined in the RNDF may be blocked. These conditions must be interpreted and adapted to by the autonomous vehicle.

2.0 Route Network Definition File (RNDF)

All Urban Challenge missions must be completed using only the roads specified in the RNDF. Vehicles may not travel off these roads. Within zones (defined below), vehicles must stay within that zone's defined perimeter. Unique RNDFs will be used for the site visits, NQE, and Urban Challenge final event. For the NQE events, a single RNDF may be used to represent multiple separated testing or practice areas, and in this case the NQE route network will not be simply connected.

2.1 Road Segments

A road network includes one or more road segments, each of which comprises one or more lanes. The basic road segment scheme is shown in Figure 1. A 'segment' is characterized by the number of lanes and the street name. A 'lane' is characterized by the nominal width of the lane, the lane markings, and the ordered set of waypoints associated with the lane. 'Waypoints' are generally placed at the center of the lane, although this may not be the optimal travel path if

parked vehicles or other obstacles are present. Travel proceeds from waypoint to successive waypoint in a lane.

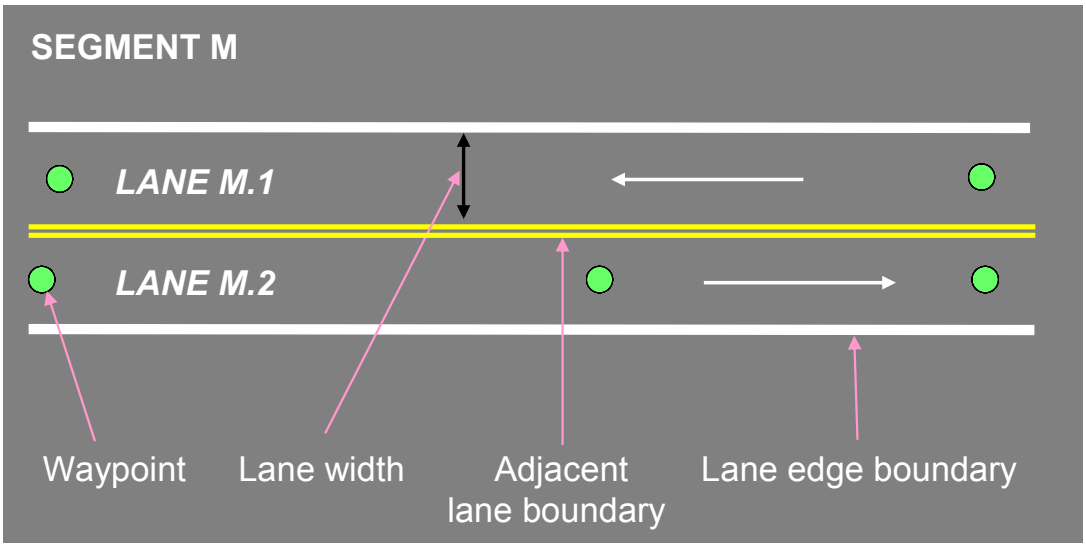

Figure 1 A road segment (Segment M) comprised of two lanes. Lanes do not necessarily have the same number of waypoints.

Every element in the RNDF is specified by a unique identifier in one of the following forms: 'M', 'M.N', or 'M.N.P', where M, N, and P are positive whole numbers. Segments are identified using the form 'M'. The N^{th} lane of segment M has the identifier 'M.N'. The waypoints of each lane are similarly identified such that the P^{th} waypoint of lane M.N is 'M.N.P' (see Figure 2).

The lane width is an optional field and will not always be specified. The 'lane width' does not guarantee the actual width at every point along a lane.

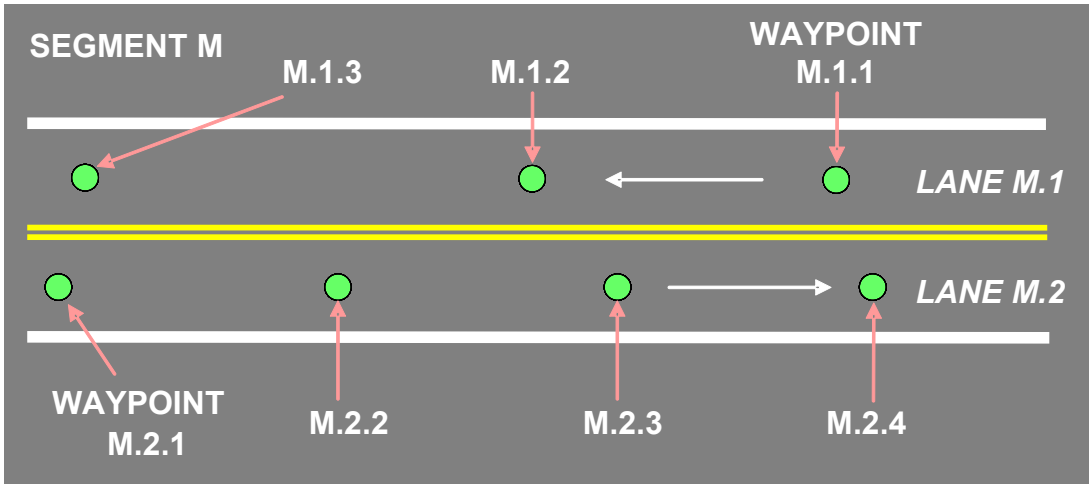

Figure 2 Waypoint numbering scheme for Segment M.

Connections between lanes are explicitly stated in the RNDF using exit and entry waypoint designations. An 'exit waypoint' is a waypoint from which the vehicle may proceed to one or

more entry waypoints. 'Entry waypoints' are located (in most cases) in neighboring road segments or zones. Entry and exit waypoints may occur in the beginning, middle, or end of a lane. Figure 3 shows an intersection in which an exit waypoint (D) at the end of lane 2.2 is associated with entry waypoints A and E in lanes 1.1 and 1.2, respectively. In addition, exit waypoints B and F in the middle of lanes 1.2 and 1.1 are associated with the entry waypoint C at the beginning of lane 2.1. Along the travel paths in the intersection (D to A, for example), there is an implied travel lane that has a width equal to the minimum of the widths of the entry and exit lanes.

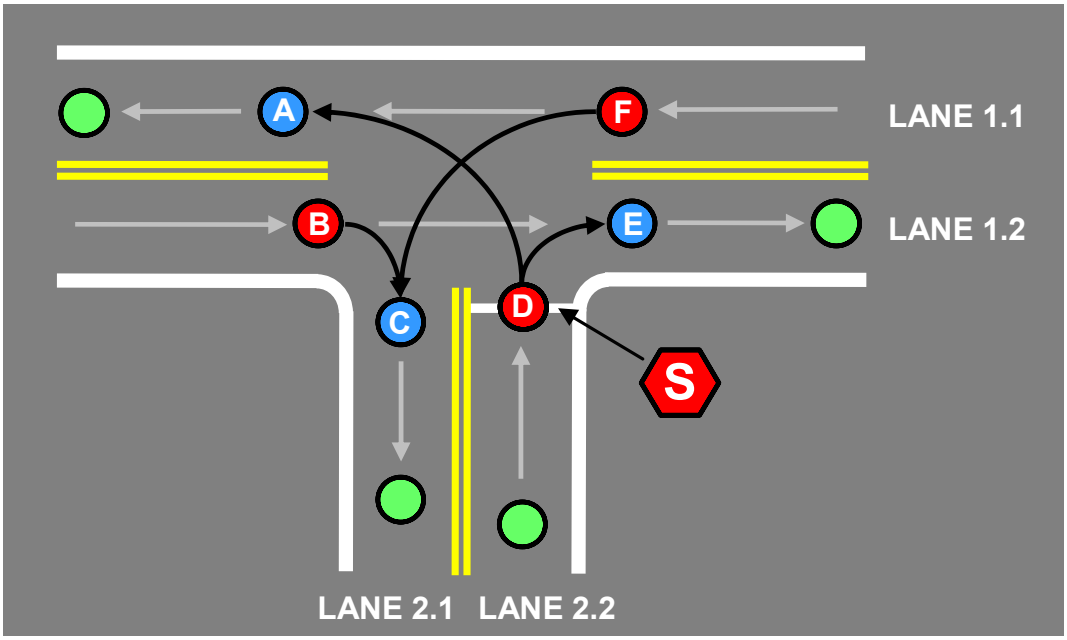

Figure 3 Stop sign intersection of Segment 2 and Segment 1. Red dots are exit waypoints, blue dots are entry waypoints, and green dots are other waypoints.

Exit and entry waypoints will not always be in different road segments or lanes. For example, the first and last points of a lane in a circular road could be an exit and entry waypoint pair. In the case of a dead end road, the last waypoint in a lane headed toward the dead end could point to the first waypoint in the adjacent lane leaving the dead end in the opposite direction. In this case, the implied behavior is a U-turn.

Stop signs are indicated in the RNDF and are associated with a single waypoint. In Figure 3, the stop sign is associated with waypoint D and is interpreted as a stop line passing through waypoint D and perpendicular to the direction of travel.

On road segments, checkpoints are associated with single waypoints. To visit a checkpoint, the front of the vehicle must pass over the checkpoint in the corresponding road segment and lane. A checkpoint will always be located at a point that can be reached by a vehicle.

For some road segments, the RNDF will specify sparsely placed waypoints. Within these segments, the implied vehicle behavior requirement is to use road-following techniques to stay in the appropriate travel lane, finding the drivable path to the next checkpoint.

2.2 Zones

In addition to segments, RNDFs may specify 'zones', areas within which free vehicle movement is permitted. The zone area is determined by a polygonal boundary defined by 'perimeter points'. Moving and stationary obstacles may exist within a zone, and the entire zone is not guaranteed drivable. Some perimeter points are identified as entry and exit points to the zone area (see Figure 4).

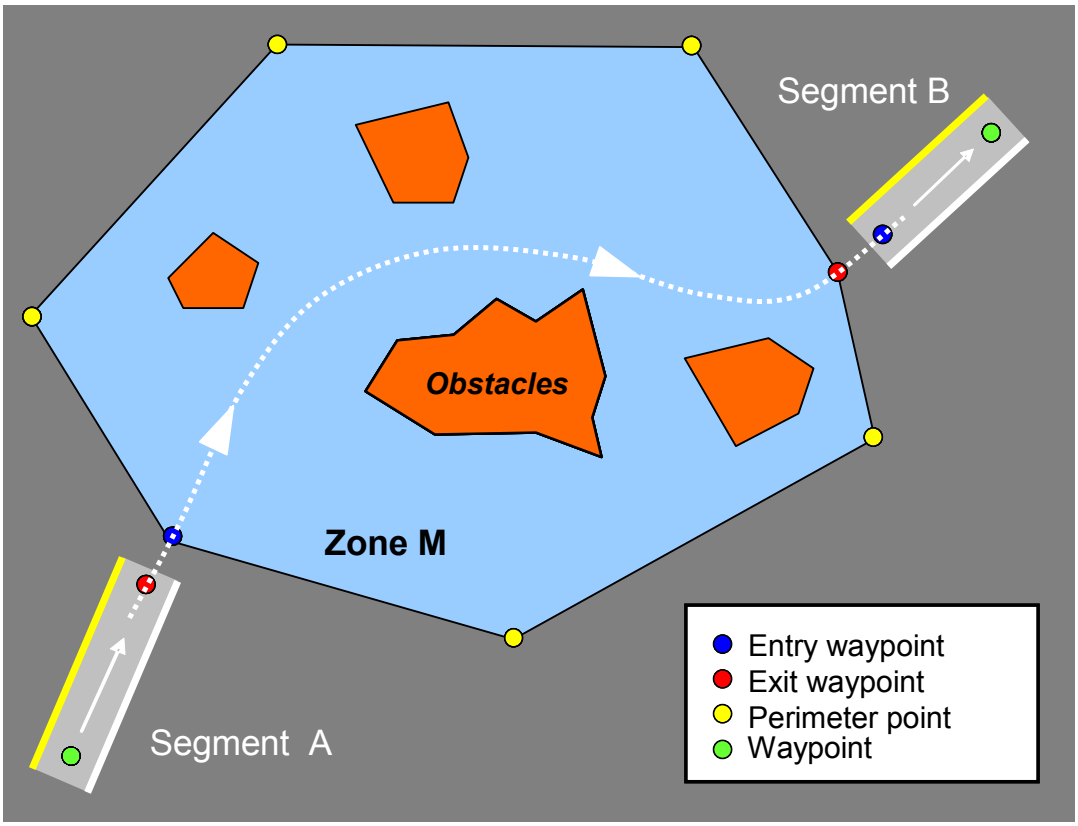

Figure 4 Zone M contains obstacles that may be moving or stationary, but whose locations are unspecified. The yellow, blue, and red dots that create the polygonal zone are perimeter points, some of which are also entry and exit points to adjacent segments. The dotted line shows one of many possible travel paths.

A zone may include one or more parking 'spots', each specified by a pair of waypoints. The second waypoint of a parking spot is always a checkpoint and is located in the center of the spot. At a parking spot, the required behavior is for the vehicle to pull over the first waypoint to the checkpoint, reverse out of the spot, and proceed to the next checkpoint in the mission, as illustrated in Figure 5.

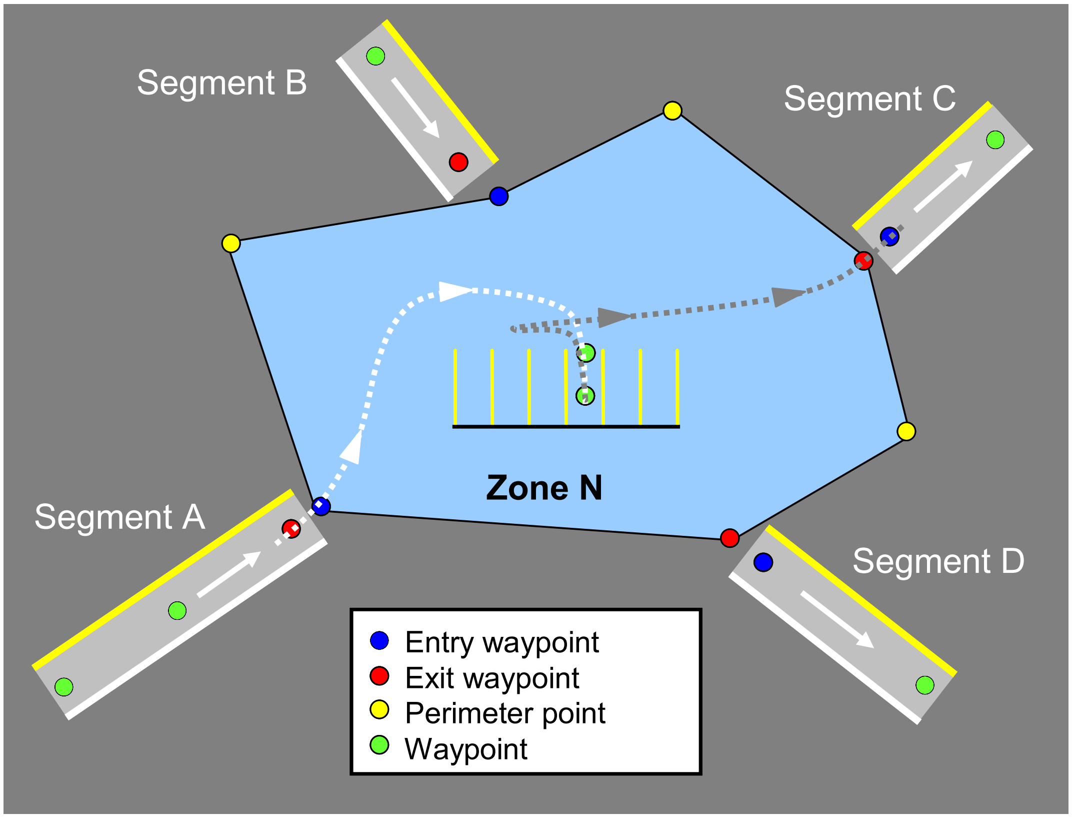

Figure 5 A vehicle enters Zone N from the exit waypoint of Segment A, moves freely to the indicated parking spot, pulls up to the checkpoint of the spot, reverses out of the spot, and proceeds to the next checkpoint on its mission.

2.3 RNDF Format

2.3.1 General

The RNDF is a tab-delimited ASCII file of the following form:

RNDF_name *filename (string)*
num_segments *number_of_segments (integer>0)*
num_zones *number_of_zones (integer≥ 0)*
<optional file header>
<segment 1>
.
.
<segment M>
<zone M+1>
.
.
<zone M+N>
end_file

The <*optional file header*> may include the following:

format_version *format_version (string)*
creation_date *creation_date (string)*

These optional file header fields are provided for convenience, and the format is unspecified. Blank lines may be added to the file for formatting purposes. C++ style comments can appear anywhere in the file, delimited by "/*" and "*/".

2.3.2 Segments

Each <*segment*> has the following format:

segment *segment_id (integer>0)*
num_lanes *number_of_lanes (integer>0)*
<*optional segment header*>
<*lane 1*>
.
.
<*lane N*>
end_segment

The <*optional segment header*> may contain the following element:

segment_name *segment_name (string)*

The *segment_name* attribute of the segment is used for the street name, such as "Wisconsin_Ave".

2.3.3 Lanes

Each <*lane*> has the following format:

lane *lane_id (x.y; x,y∈ integer>0*)
num_waypoints *number_of_waypoints (integer>0)*
<*optional lane header*>
<*waypoint 1*>
.
.
<*waypoint P*>
end_lane

The *lane_id* is constructed from the number of the segment in which it is contained. For example, if segment 17 has two lanes, they would be named "17.1" and "17.2". The general naming convention numbers adjacent lanes consecutively from west to east or north to south. If segment 17 in the example moves in an east-west direction, the north lane would be named "17.1" and the south lane "17.2."

The <*optional lane header*> contains some or all of the following elements:

lane_width	*lane_width (integer≥ 0)*
left_boundary	*left_boundary (string* ∈ {double_yellow, solid_white, broken_white})
right_boundary	*right_boundary (string*∈ {double_yellow, solid_white, broken_white})
checkpoint	*waypoint_id (x.y.z; x,y,z*∈ *integer>0*) *checkpoint_id (integer>0)*
stop	*waypoint_id (x.y.z; x,y,z*∈ *integer>0*)
exit	*exit_waypoint (waypoint_id*) *entry_waypoint (waypoint_id)*

The *lane_width* provides the width of the lane in feet. The keyword **checkpoint** indicates that the waypoint is a named checkpoint. The keyword **stop** indicates a waypoint associated with a stop sign. The keyword **exit** is followed by the name of the *exit_waypoint* and related *entry_waypoint* associated with the lane. A lane may have multiple checkpoints, stop signs, entry waypoints, or exit waypoints.

2.3.4 Waypoints

A <*waypoint*> has the following format:

waypoint_id (x.y.z; x,y,z∈ *integer>0*) *latitude (float)* *longitude (float)*

The *waypoint_id* is constructed from the *lane_id*. The first waypoint of lane 17.1 is thus named "17.1.1". The *latitude* and *longitude* fields are floats with six decimal places and represent points in the WGS84 coordinate system. Points in the northern and western hemispheres have positive latitude and negative longitude, respectively.

2.3.5 Zones

Each <*zone*> has the following format:

zone *zone_id (integer>0)*
num_spots *number_of_parking spots (integer>0)*
<*optional zone header*>
<*perimeter*>
<*spot 1*>
.
.
<*spot N*>
end_zone

The integers used to identify zones and segments are unique and sequential.

The <*optional zone header*> may contain the following element:

zone_name *zone_name (string)*

The *zone_name* attribute of the header is used to designate the zone, such as "North_Parking_Lot".

2.3.6 Zone Perimeter

The <*perimeter*> has the following format:

perimeter *perimeter_id (x.0; x∈ integer>0*)
num_perimeterpoints *number_of_perimeterpoints (integer>0)*
<*optional perimeter header*>
<*perimeterpoint 1*>
.
.
<*perimeterpoint P*>
end_perimeter

The *perimeter_id* is an extension of the *zone_id* and always ends with a zero. For zone 23, for example, the *perimeter_id* is "23.0." The *perimeter_id* is an artifice to ensure a uniform naming scheme for all elements.

The <*optional perimeter header*> may contain the following element:

exit *exit_perimeterpoint (perimeterpoint_id)* *entry_waypoint (waypoint_id)*

The keyword **exit** is followed by the name of *exit_perimeterpoint* and related *entry_waypoint* associated with the lane of an adjacent segment. A given zone may have multiple entry or exit waypoints.

A <*perimeterpoint*> has the following format:

perimeterpoint_id (x.0.z; x,z∈ integer>0) *latitude (float)* *longitude (float)*

The *perimeterpoint_id* is constructed from the *perimeter_id* of the perimeter that contains it and its position in relation to other perimeterpoints. The northernmost perimeterpoint of zone 23 is named "23.0.1", and the successive perimeterpoint in the clockwise direction are "23.0.2" and so on. The *latitude* and *longitude* fields are floats with six decimal places and represent points in the WGS84 coordinate system.

2.3.7 Zone Parking Spots

Each <*spot*> within a zone has the following format:

spot *spot_id (x.y; x,y∈ integer>0*)
<*optional spot header*>
<*waypoint 1*>
<*waypoint 2*>
end_spot

The *spot_id* is constructed from the *zone_id* of the zone in which it is contained. Thus, the first spot in zone 23 would be named "23.1". Adjacent spots are numbered consecutively from north to south and east to west, similar to the lane-numbering convention.

The *optional spot header* contains some or all of the following elements:

spot_width	*spot_width (integer>0)*
checkpoint	*waypoint_id (x.y.z; x,y,z∈ integer>0) checkpoint_id (integer>0)*

The *spot_width* provides the width of a spot in feet. The keyword **checkpoint** indicates the waypoint is a named checkpoint.

The *waypoints* that define the spot have the same format as that used for lane waypoints:

waypoint_id (x.y.z; x,y,z∈ integer>0) latitude (float) longitude (float)

The *waypoint_id* is constructed from the *spot_id* of the spot in which it is contained. Thus, the first waypoint of spot 23.1 would be named "23.1.1", and the second "23.1.2". As a rule, each spot consists of only two consecutive waypoints, thus defining the direction and length of a spot. By convention, the second waypoint of every spot is a checkpoint.

3.0 Mission Data File (MDF)

The MDF describes a sequence of checkpoints to be visited in order by the vehicle. Every MDF is interpreted with respect to a specific RNDF, and many different MDFs may be associated with the same RNDF.

3.1 Checkpoints

As defined in the RNDF, a checkpoint is a labeled waypoint. A checkpoint is considered visited if the vehicle traverses over the checkpoint in the correct lane or parking spot (Figure 6) in the proper direction.

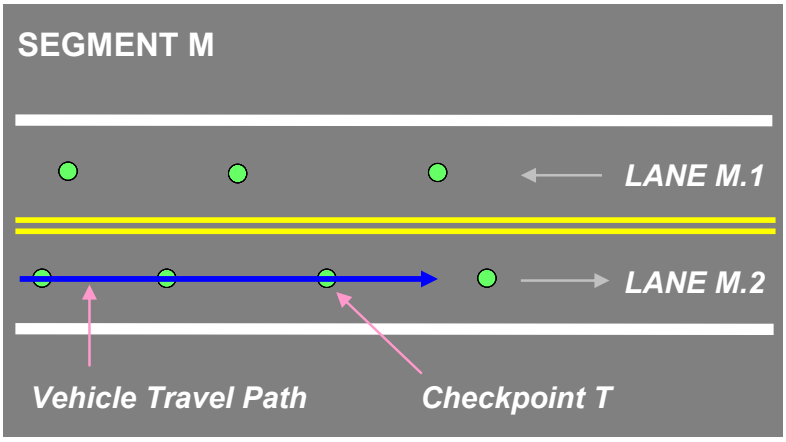

Figure 6 A vehicle visits Checkpoint T by traveling in the direction of the lane where the checkpoint is located.

The MDF may specify a checkpoint more than once in a mission. Not all checkpoints identified in the RNDF will necessarily be included in a mission. As a rule, the last checkpoint in the MDF serves as the finish line for that mission, and the vehicle must come to a complete stop at this checkpoint.

3.2 Speed Limits

The MDF contains a speed limit assignment for each road segment and zone and applies to all lanes of a segment or the area of a zone. Speed limits are assigned a minimum and maximum. A minimum or maximum speed of "0" indicates that the minimum or maximum speed is undefined for that segment or zone. When the value of minimum speed is identical to the maximum speed, vehicles are required to maintain that speed for the segment or zone.

3.3 MDF Format

The MDF is a tab-delimited ASCII file of the following format:

MDF_name *filename (string)*
RNDF *RNDF_name (string)*
<optional file header>
checkpoints
num_checkpoints *number_of_checkpoints (integer>0)*
<checkpoint 1>
.
.
<checkpoint L>
end_checkpoints
speed_limits
num_speed_limits *number_of_speedlimits (integer>0)*
<speed_limit 1>
.
.
<speed_limit M>
end_speed_limits
end_file

The *RNDF_name* field is the name of the RNDF associated with the MDF.

Blank lines may be added to the file for formatting purposes. C++ - style comments can appear anywhere in the file, delimited by "/*" and "*/".

The <*optional file header*> may contain:

format_version *format_version (string)*
creation_date *creation_date (string)*

Each mission <*checkpoint*> has the following form:

checkpoint_id (integer>0)

where the *checkpoint_id* is defined in the RNDF.

Each <*speed_limit*> has the following form:

id (integer>0) *min_speed (integer≥ 0)* *max_speed (integer≥ 0)*

where *id* is either a *segment_id* or a *zone_id*. Both the *min_speed* and *max_speed* are given in miles per hour.

4.0 Sample RNDF and MDF

To illustrate the file formats described in this document, a Sample RNDF and Sample MDF are available. Accompanying these files is a Sample RNDF Map which provides a graphical representation of the Sample RNDF. All files are available for download at www.darpa.mil/grandchallenge.